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Heat transfer to the emitter and collector of a cesium thermionic converter was measured as a function of emitter temperature, cesium pressure and current. The converter [1] has a cylindrical geometry emitter of vapor-deposited tungsten with an effective emitting area of 14 cm^2 that is cold-spaced 10 mil from a molybdenum collector.

Energy-transfer data in Fig. 1 show curves of total heat to the emitter, Q_F, and the heat to the collector calorimeter, Q_C, as a function of current density, J, at constant emitter, collector, and cesium reservoir temperatures. Equation (1) gives an energy balance for the emitter heat input.

$$\underbrace{Q_F}_{\text{Total heat to emitter}} = \underbrace{IV}_{\text{Electrical power at electrodes}} + \underbrace{Q_C}_{\text{Waste heat to collector (radiation, Cs conduction and electron)}} + \underbrace{Q_{EL}}_{\text{Emitter structure heat losses}} \qquad (1)$$

Rearrangement of Eq. (1) and transformation to a difference equation with respect to the cell current, I, gives

$$\frac{\Delta Q_C}{I} = \frac{\Delta Q_F}{I} - \frac{\Delta(IV)}{I} - \frac{\Delta Q_{EL}}{I} , \qquad (2)$$

where $\Delta Q = Q(I) - Q(I{=}0)$. The emitter structure heat loss, Q_{EL}, is dependent on current through joule heating of the emitter stem. Heat transfer calculations show one-half the joule heating in the emitter stem, IV_s, is effectively returned to the emitter, or

$$\frac{\Delta Q_{EL}}{I} = -1/2\ V_s . \qquad (3)$$

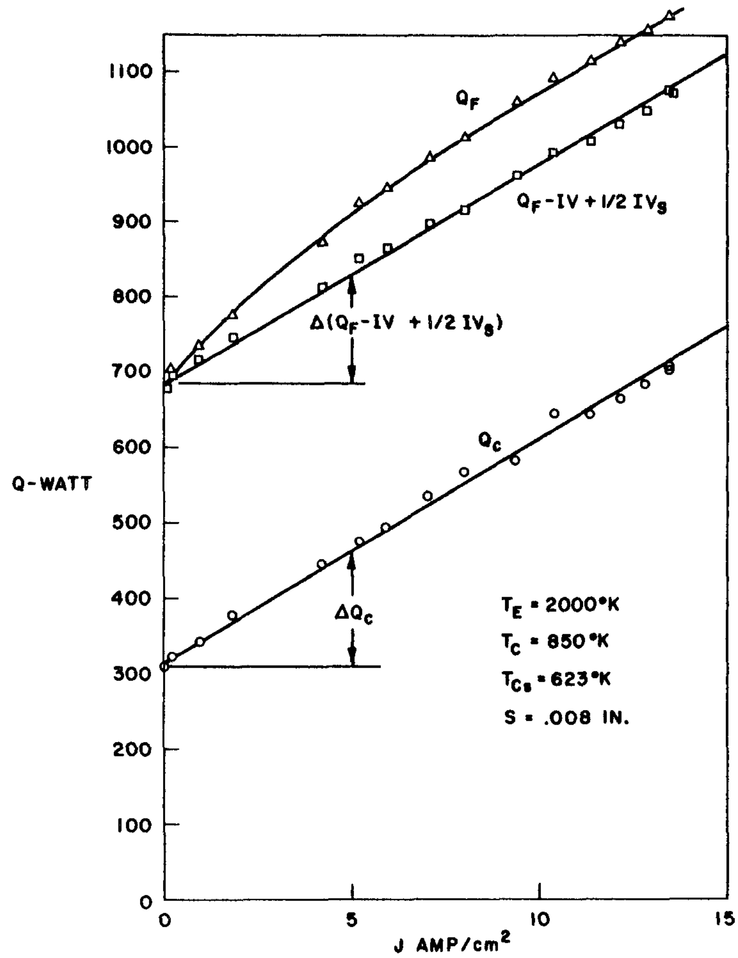

Fig. 1--Experimental demonstration of emitter-collector energy balance

Substitution of (3) into (2) gives an expression for $\Delta Q_C/I$ in terms of experimentally determined quantities

$$\frac{\Delta Q_C}{I} = \frac{\Delta Q_F}{I} - V + 1/2\ V_s. \tag{4}$$

The calculated quantity on the right of Eq. (4) is the slope of the (Q_F - IV + 1/2 IV_s) curve in Fig. 1 which is shown to be equal to the slope of the Q_C curve within experimental errors and therefore demonstrates the energy balance of Eq. (4). Of particular significance is that the slope of the Q_C line, $\Delta Q_C/I$, is a constant 2.1 V from 0 to 15 A/cm^2. This means that the waste heat transferred to the collector per electron is a constant. Values of the constant $\Delta Q_C/I$ were determined on two other converters over a wide range of operating variables.[1] Figure 2 shows $\Delta Q_C/I$ for the converter OC-5 as a function of cesium pressure for a constant emitter and collector temperature. It is noted that $\Delta Q_C/I$ exhibits a minimum at a cesium pressure of 5 torr. As shown in the top of Fig. 2, this closely corresponds to the cesium pressure experimentally found to give a maximum electrode voltage at the optimum cell current for maximum power output.

Physically $\Delta Q_C/I$ is the sum of the effective collector work function, ϕ_C, the average kinetic energy per electron leaving the emitter, $2kT_E/e$ and an accelerating voltage, V_x, corresponding to difference between the effective barrier heights of the emitter and collector.

$$\frac{\Delta Q_C}{I} = \phi_C + \frac{2kT_E}{e} + V_x \tag{5}$$

Subtacting ϕ_C values [2] and $2kT_E$ from $\Delta Q_C/I$ in Fig. 2, the difference V_x also exhibits a minimum which at a cesium pressure of 6 torr is very small. This small magnitude of V_x is less than expected when the converter electron energy balance in Eq. (6) is considered.

$$\phi_E = V_d + \phi_C + V \tag{6}$$

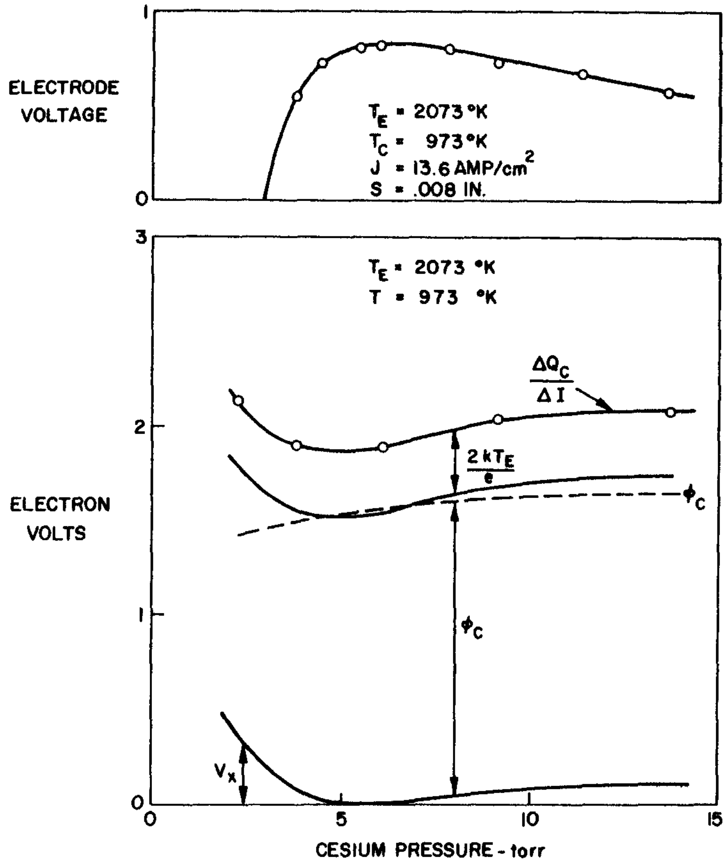

Fig. 2--Collector electron heating (lower graph) and electrode voltage (upper graph) versus cesium pressure at a constant emitter and collector temperature

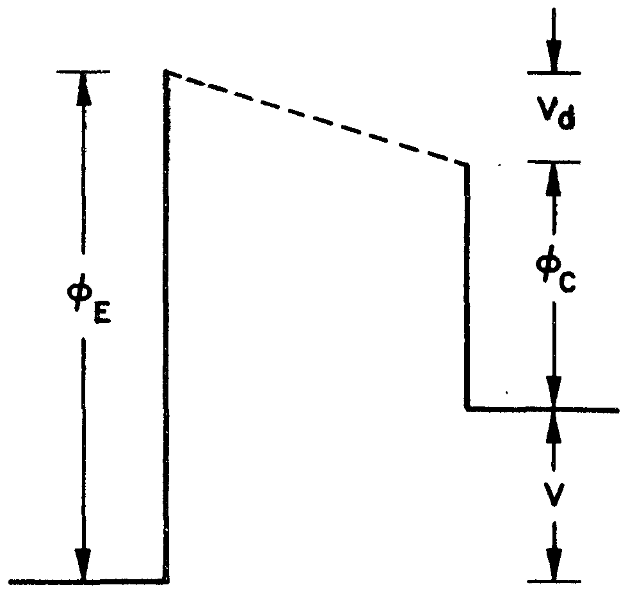

Fig. 3--Electron motive diagram for definition of terms in Eq. (6)

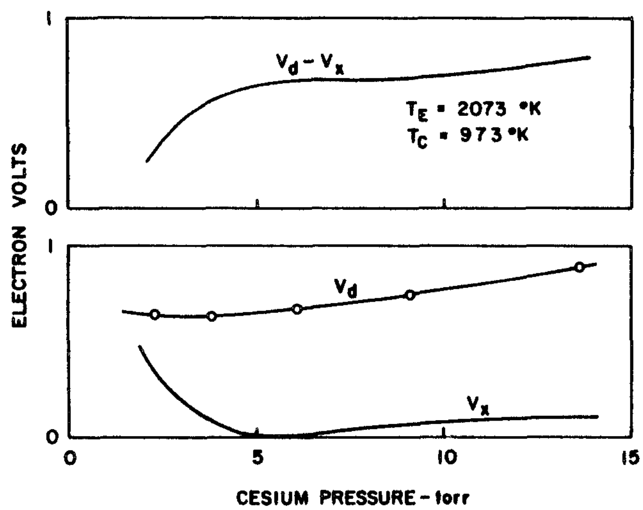

Fig. 4--Energy returned to emitter (V_d - V_x) and energy leaving emitter V_d versus cesium pressure

The terms are identified in the motive diagram of Fig. 3 where the cell voltage is defined positive for a power producing converter. Shown in Fig. 4 are values of V_d that were calculated by Eq. (6) using the experimental voltage, V, the effective emitter work function values, ϕ_E, for cesiated tungsten derived [3] from the experimental data of Houston and of Langmuir and Taylor, and the effective collector work function values shown in Fig. 2. It appears that energy in the amount of $(V_d - V_x)$ does not arrive at the collector and must therefore be returned to the emitter as heat if the electrode effective work functions are correct. A similar effect was observed by Houston,[4] which he explained as energy return to the emitter from the plasma with the primary mode of heat transfer by recombination of ions at the emitter. Thus, it is proposed that the electron energy $(V_d - V_x)$ is primarily dissipated in the ionization of cesium.

In Fig. 4 it is shown that V_x is larger at off-optimum cesium pressures. For cesium pressures greater than 6 torr, V_x proportionally increases with V_d. At lower than optimum cesium pressures, a much larger fraction of V_d arrives at the collector. This is expected since fewer electron-cesium collisions are experienced in the vicinity of the emitter.

Conclusions

From measurements of heat transfer to the collector of a cesium thermionic converter, it was found that the electron waste heat to the collector is constant for a given emitter, collector, and cesium reservoir temperature. Electron energy return to the emitter up to 0.8 ev is explained by electron energy dissipation in collisions with cesium atoms with the energy returned to the emitter by ion recombination. It was found that the minimum electron waste heat delivered to the collector coincided with the optimum cesium pressure.

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